Wind and Seismic Effects

Proceedings of the 30th Joint Meeting

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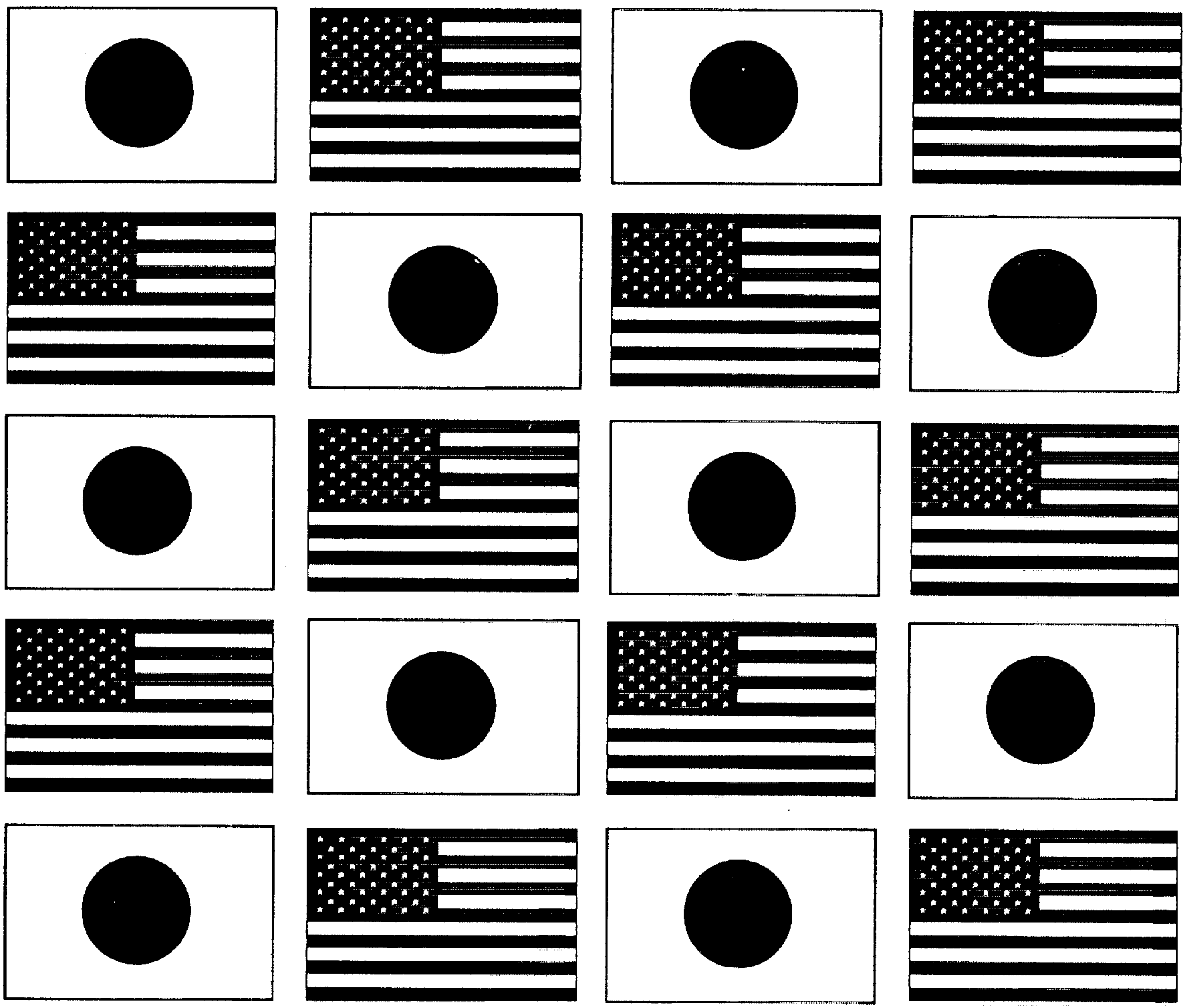

U.S. DEPARTMENT OF COMMERCE
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Wind and Seismic Effects

NIST SP 931

PROCEEDINGS OF THE 30TH JOINT MEETING OF THE U.S.-JAPAN COOPERATIVE PROGRAM IN NATURAL RESOURCES PANEL ON WIND AND SEISMIC EFFECTS

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WIND ENGINEERING

Wind and Seismic Research for Improved Engineering Consensus Standards and Housing Construction

by

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ABSTRACT

This paper provides an overview of recent engineering research that has resulted in improved engineering standards, design methods, and building codes for the construction of housing and other types of buildings in the United States. The engineering advancements include the development of a new hurricane wind map, new load and directionality factors for wind, and a new method of analyzing wood-frame shear walls.

KEYWORDS:

Houses, Engineering, Research, Wind, Seismic, Consensus Standards, Building Codes

1. INTRODUCTION

Housing construction in the United States has become subject to increased scrutiny with respect to its performance in high wind and earthquake risk regions. As a result of this scrutiny the need for affordable and simple construction methods has been challenge by the need to improve the safety of these buildings. The focus of this summary paper is to give a broad overview of recent efforts to improve the safety of residential buildings while maintaining affordability and simplicity of construction methods or regulations.

Over the past two years, the National Association of Home Builders and the U.S. Department of Housing and Urban Development have joined in a multi-year cooperative program to address the safety and affordability of future housing in the United States. The title of the program is *Housing Affordability Through Design Efficiency* (HATDE). The program is under the management of the NAHB Research Center, Inc. Other partners have included State Farm Insurance Companies, Applied Research Associates, Virginia Polytechnic Institute and State University, Johns Hopkins University, Clemson University, and Andersen Corporation. The program has extended recent research funded by other institutions such as the National Science Foundation and the U.S. Department of Agriculture to applications related to efficient design of residential buildings and other types of structures.

2. OVERVIEW OF THE HATDE PROGRAM

The objective of the HATDE program is simply stated as follows:

"To conduct practical research activities which support the development and implementation of innovative and efficient engineering principles and construction practices in support of reasonably affordable and safe housing in all hazard conditions in the United States."

To meet this objective a comprehensive research agenda was developed and continues to be subject to review and input from a broad-based research coordination group. The research program and agenda encompasses the following major elements:

[1]NAHB Research Center, Inc., 400 Prince George's Boulevard, Upper Marlboro, MD 20774-8731.

[2]U.S. Department of Housing and Urban Development, 451 Seventh Street, SW, Washington, D.C. 20410.

- Coordination

  Research Coordination Group (90 representatives)

  Peer Review Group (6 experts in engineering, architecture, and housing)

- Research Areas

  Loads
  Resistance (Strength)
  Performance Assessment
  Quality/Defects Analysis

- Dissemination

  Building Codes
  Engineering Standards
  Education & Demonstration
  Publication/Reports/Articles

The research coordination effort serves several purposes including identification and prioritization of research needs, dissemination of research findings, coordination with similar research programs and initiatives, and development of partnerships. Research activities are selected from the research agenda based on priority and funding availability among the collaborators. A smaller peer review group assists in the direction of program funding and critical review of research activities, plans, results, and proposed applications. The program is specifically designed to address research needs in a manner that will have the most immediate and effective impacts on improving residential construction and design practices. The underlying principle is that more efficient engineering approaches will result in improved performance of homes (relative to current day practices) without adversely impacting the cost of construction or housing affordability.

The remainder of this paper will present the key research and dissemination activities accomplished to date in the HATDE program.

3. STRUCTURAL LOADS (WIND)

A major emphasis in the formation of the HATDE program was related to wind loads, particularly in hurricane prone regions. This emphasis was associated with the construction cost impacts realized when homes were subject to engineered design using existing engineering load standards such as the American Society of Civil Engineer's standard Minimum Design Loads for Buildings and Other Structures (ASCE 7)[1]. Because of this concern two projects were directed toward research needs which would improve the accuracy of this wind load standard when applied to homes and other structures.

The first project focused on the development of a hurricane coast wind map that utilized the latest advancements in hurricane wind field and risk modeling [2][3]. Using these models which were validated by data from numerous actual hurricane events, Applied Research Associates (Raleigh, NC) produced a new generation design wind map for the hurricane coast regions of the United States. The map shown in Figure 1 is essentially the same map that is now being considered for approval in the ASCE 7 consensus standard. It is important to note that the new map results in a faster degradation of hurricane wind contours over land. This shift of the wind contours toward the coast is a result of the more accurate hurricane wind field modeling.

The second project related to wind loads re-evaluated the wind load factor for probability-based design formats such as Load and Resistance Factor Design (LRFD). LRFD load combinations are supported in the ASCE 7 standard and they are advancing in application to residential construction with the advent of LRFD provisions for wood construction [4]. The load factor study included a delphi process of wind engineering experts in the United States to help identify the latest knowledge regarding the stochastic parameters related to wind loads. Also included in this work was the investigation of a wind directionality factor that adjusts wind loads to account for the probability that wind will not always come from a direction that produces the worst-case wind effect on any particular structure or its components.

As a result of this work a new wind load factor and a separate directionality factor is being proposed for inclusion in the next version of the ASCE 7 consensus standard. The previous wind load factor of 1.3 included a 0.85 factor adjustment for directionality. By removing the 0.85 directionality factor, the wind load factor would numerically change to 1.5 (1.3/0.85 = 1.5). This change was also supported by the re-analysis of the wind load factor using the delphi results and principles of uncertainty [5]. The directionality factor is then treated as an adjustment parameter (depending on shape of the structure) when calculating the nominal (50-year return period) wind load. Based on this work, a possible representation of a wind load combination and the wind velocity pressure equation might be as follows:

$$0.9D + 1.5W$$

$$q = 0.613 K_z K_{zt} K_d V^2 I$$

where,

D = dead load
W = wind load
q = wind velocity pressure (N/m^2)
K_z = exposure coefficient
K_{zt} = topographic factor
K_d = directionality factor of 0.85
V = nominal design wind speed (m/s)
I = building importance factor

Other research has shown that the load factor should be higher for hurricane prone regions. The final outcome of these changes will be forthcoming through the ASCE 7 consensus standard balloting process.

4. STRUCTURAL RESISTANCE

A major focus in the area of seismic design and wind resistance of wood-frame homes has been in the area of wall bracing or the lateral force resisting system (LFRS). The major components of the LFRS of a home are light-frame shear walls with wood structural panels. Of course, the performance of these walls is dependent on the manner of restraining the walls against rotation. Common practice is to include hold-down brackets and special metal connectors to transfer overturning loads to the building foundation. Other fasteners, including nails, anchor bolts, and shear plates, transfer shear loads collected by horizontal diaphragms (floors and roofs) to the shear walls. Similarly, the base of the shear wall is connected to the walls or foundations below. While this scheme provides a reasonably simple method of engineering analysis, it is not the most efficient practice for relatively light residential buildings such as single-family detached homes.

To improve the efficiency of designing the LFRS of homes, a shear wall research project was initiated in the HATDE program. The project was designed to build on previous research on the perforated shear wall method [6]. By this method, an engineer may readily and accurately determine the strength of a fully-sheathed wall with openings, and hold-downs are only required at the ends of the walls. While resulting in a moderate reduction in capacity compared to a wall with hold-downs restraining each full-height segment, it provides sufficient strength for many light-frame residential construction applications, even in high wind and seismic conditions. The perforated shear wall method was first developed by researchers in Japan over 20 years ago [7].

The HATDE program expanded the work to include investigation of perforated walls with full restraint of each segment and with no restraint other than conventional anchor bolts through the sill plates. These tests included numerous opening configurations in walls that were 12.2 m (40 ft) long. Both cyclic and monotonic loading conditions were investigated [8][9]. Finally, four walls of a 3.7m (12 ft) length with corner framing and no hold-down restraints were subjected to the cyclic loading test protocol [10]. The unit shear strength obtained in these tests was more than 85 percent of that achieved with the fully restrained walls previously tested. This finding is a strong indication that corners may be considered as providing adequate shear wall restraint when properly designed and detailed. This phenomenon is known as the "corner effect". The testing information has been used to assist in the development of improved wall bracing provisions of the proposed *International Residential Code*.

Additional tests have been recently completed that investigate the inclusion of narrow wall segments within a fully-sheathed perforated shear wall (NAHB Research Center, Inc., unpublished report). The tests also investigated walls with garage door openings having narrow shear wall segments and varying degrees of framing enhancements relative to conventional framing practices. One pilot test was conducted to investigate the effect of reduced base restraint of the perforated shear wall (i.e. anchor bolt spacing increased from 0.6 m (2 ft.) to 1.8 m (6 ft.)). An additional pilot test looked at enhancement of shear wall performance using strategically placed metal truss plates at the wall and window corners. The walls tested in these recently completed tests are shown in Table 1.

The preliminary results of these later tests indicate that the perforated shear wall design method is applicable to walls with narrow aspect ratio wall segments (i.e. a 4:1 ratio of height to width of segments between openings). However, the opening heights adjacent to the 4:1 aspect ratio wall segments were limited to 50 percent of the total wall height in these tests. Also, some very economical and simple enhancements to garage opening framing can provide useful design solutions in relatively high lateral loading conditions. Increasing the anchor bolt spacing on the sill plates had a negligible effect on the perforated shear wall capacity and stiffness for the pilot test. Additional testing will be conducted to better quantify the effects of further reductions to the base restraint of perforated shear walls. Finally, the use of metal truss plates to reinforce key joints in the wall framing enhanced the shear wall performance by as much as 40 percent

5. SUMMARY AND CONCLUSIONS

In the first two years of the HATDE program, several research activities related to structural loads and resistance has been conducted to improve the efficiency of engineering residential buildings. The findings have been implemented in engineering consensus standards and in the development of new residential building code provisions in the United States. The following conclusions can be drawn from these efforts:

1. The resistance (strength) of residential construction, particularly the lateral force resisting system, is significantly underestimated (or not optimized) with current engineering methods of design. Future efforts should continue to develop and apply innovative engineering approaches that better quantify the lateral strength of light-frame residential buildings. From this work the design of residential buildings for high wind and seismic conditions will be addressed in an optimal fashion.

2. Wind loads in hurricane coastal regions have been improved by implementing improved models for hurricane winds as they degrade over land.

3. A new study on a wind load factor and wind directionality will result in a more tractable and risk-consistent design method for determining wind loads on various types of structures.

6. REFERENCES

[1] *American Society of Civil Engineers Minimum Design Loads for Building and Other Structures*, American Society of Civil Engineers, New York, NY (1995).

[2] Vickery, P.J., P.F. Skerlj, A.C. Steckley, and L.A. Twisdale, *Hurricane Wind Field and Gust Factor Models for Use in Hurricane Wind Speed Simulations*, Applied Research

Associates, Raleigh, NC (1997) pending publication.

[3] Vickery, P.J., P.F. Skerlj, and L.A. Twisdale, *Simulation of Hurricane Risk in the United States Using an Empirical Storm Track Modeling Technique*, Applied Research Associates, Raleigh, NC (1997) pending publication.

[4] *Load and Resistance Factor Design Manual for Engineered Wood Construction*, American Forest & Paper Association, American Wood Council, Washington, DC, (1996).

[5] Ellingwood, B. and P. Beraki, *Wind Load Statistics for Probability-Based Design*, prepared for the U.S. Department of Housing and Urban Development, the National Association of Home Builders, and the NAHB Research Center, Inc. by Johns Hopkins University, Baltimore, MD, October 1997 (pending journal publication; available through NTIS).

[6] Dolan, J. and Johnson, A., *Monotonic Tests of Long Shear Walls with Openings*, prepared for the American Forest and Paper Association by Virginia Polytechnic Institute and State University, 1996.

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[9] Dolan, J. and Heine, C., *Sequential Phased Displacement Cyclic Tests of Wood Frame Shear Walls with Various Openings and Base Restraint Configurations*, Prepared for the NAHB Research Center Inc. by Virginia Polytechnic Institute and State University, 1997.

[10] Dolan, J. and Heine, C., *Sequential Phased Displacement Tests of Wood Framed Shear Walls with Corners*, Prepared for the NAHB Research Center Inc. by Virginia Polytechnic Institute and State University, 1997.

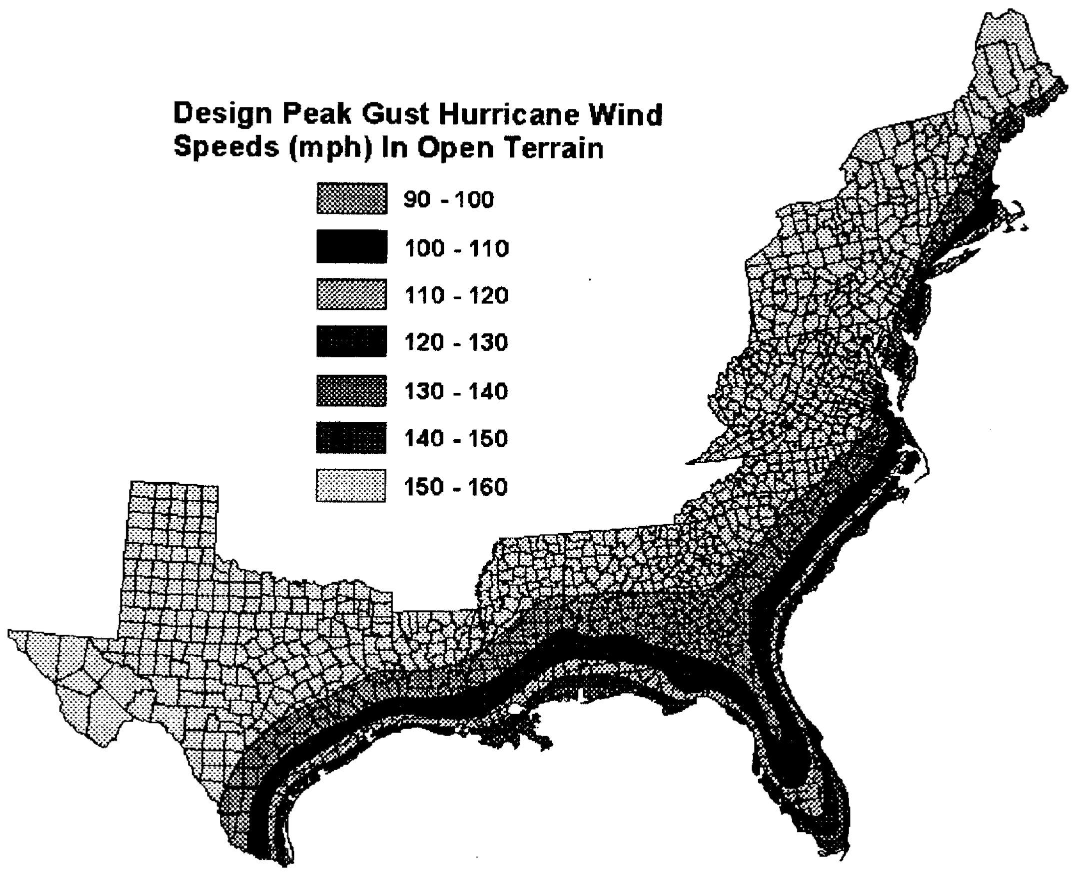
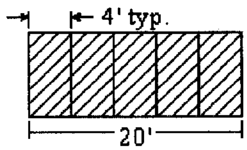
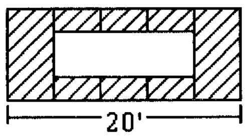
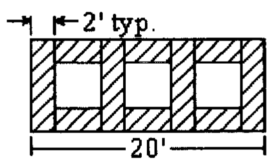
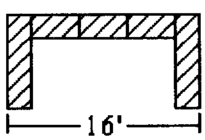
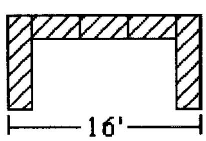
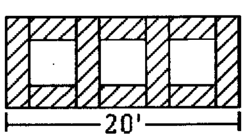
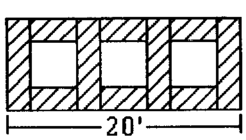


Figure 1: New Hurricane Design Wind Contours for the ASCE 7 Consensus Standard (courtesy Peter Vickery, Applied Research Associates).

Table 1: Shear Wall Configurations

Specimen	Wall Configuration	Openings	Sheathing Area Ratio, r	Anchor Bolt Spacing	Hold-downs
Wall 1		None	1.0	2' o.c.	Ends
Wall 2		(1) - 12' x 4'	0.57	2' o.c.	Ends
Wall 3		(3) - 4' x 4'	0.57	2' o.c.	Ends
Wall 4		(1) - 12' x 6'-8"	0.29	2' o.c.	Ends
Wall 5[1]		(1) - 12' x 6'-8"	0.29	2' o.c.	Ends
Wall 6[1]		(3) - 4' x 4'	0.57	2' o.c.	None
Wall 7		(3) - 4' x 4'	0.57	6' o.c.	Ends

For SI: 1 ft.(') = 0.3048 m, 1 in.(") = 25.4 mm.
[1] Alternative framing methods used.